RESEARCH DEPARTMENT

The design of a new free-field sound measurement room: The selection of sound absorbent material

RESEARCH REPORT No. L-055

1964/42

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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THE DESIGN OF A NEW FREE-FIELD SOUND MEASUREMENT ROOM: THE SELECTION OF SOUND ABSORBENT MATERIAL

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SUMMARY

In designing wedge-type sound absorbers for use in a new free-field room, various kinds of plastic foam were considered as possible alternatives to glass wool or glass fibre. The reflexion coefficient of the plastic materials was found to be influenced by mechanical resonances in the material, which in turn were markedly affected by the method of mounting the wedge. The material finally adopted was a polyurethane ether foam having sufficient mechanical hysteresis to damp the internal resonances. The introduction of additional mass in the form of a steel rod at the centre of each wedge was found to extend the low-frequency range.

1. INTRODUCTION

In the new sound measurement room built in 1963 at Kingswood Warren, it was desired to ensure substantially free-field conditions at frequencies down to 50 c/s. The acoustic treatment in the existing sound measurement room consists of glass fibre wedges 8 in. x 8 in. (20 cm x 20 cm) at the base, and occupies a depth of 3 ft 6 in. (1·1 m); from experience with this room, it was estimated that the required performance in the new room could be obtained by similar means by allowing a total of 5 ft (1·5 m) for the length of the wedge plus the air space, if any, between it and the wall. However, as an increase in length of wedge would in theory alter the optimum value of flow resistance, it was necessary to experiment with materials other than the original grade of glass fibre.

2. GENERAL

Measurements of reflexion coefficient for normal incidence were made by means of a travelling-wave duct having an internal cross-section 16 in. x 16 in. (40 cm x 40 cm) thus accommodating four wedges. Although the base cross-section of the wedge was kept constant throughout the experiments, the remaining dimensions were varied; for convenience, the length of the tapering portion of the wedge, the length of the parallel portion, the air gap between the base of the wedge and the wall and the overall depth of the acoustic treatment are designated, as shown in Fig. 1, as *A*, *B*, *C* and *D* respectively.

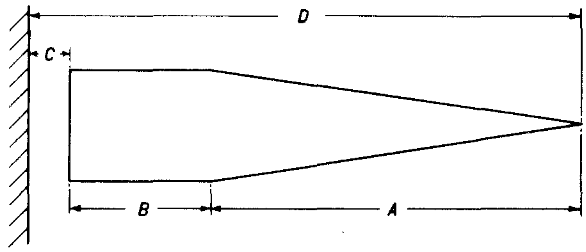

Fig. 1 - Dimensions of wedge and position relative to wall

The lower limit of the useful frequency range of an absorbent material for a free-field room is usually taken as the point at which the reflexion coefficient rises to 10%. To facilitate comparison between different types of sound absorber occupying different amounts of space, some workers have taken as a figure of merit the value of D/λ_o where λ_o is the wavelength, in air, of sound at that frequency for which the reflexion coefficient is 10%. This procedure, however, produces a figure which decreases when the working frequency range of the absorber increases; to avoid this incongruity, the inverse quantity λ_o/D will be used in the present report as a measure of the efficacy of various types of acoustic treatment.

For the sake of brevity and to preserve anonymity, commercial brands of absorbent material have been designated throughout by Roman numerals.

3. FIBROUS MATERIALS

The first group of materials to be investigated were of the fibrous type, in which the absorption of sound depends principally on the flow resistance. According to theory, the curve of reflexion coefficient as a function of frequency should exhibit signs of interference between the wave reflected from the front of the wedges and that reflected after passing through the wedges and reaching the rigid wall behind them. Fig. 2(a) shows the theoretical form of reflexion characteristic given in a paper by Walther[1] in 1960 and Fig. 2(b) the reflexion characteristic of a sample of low-density glass fibre, in which the effects of interference are likewise apparent.

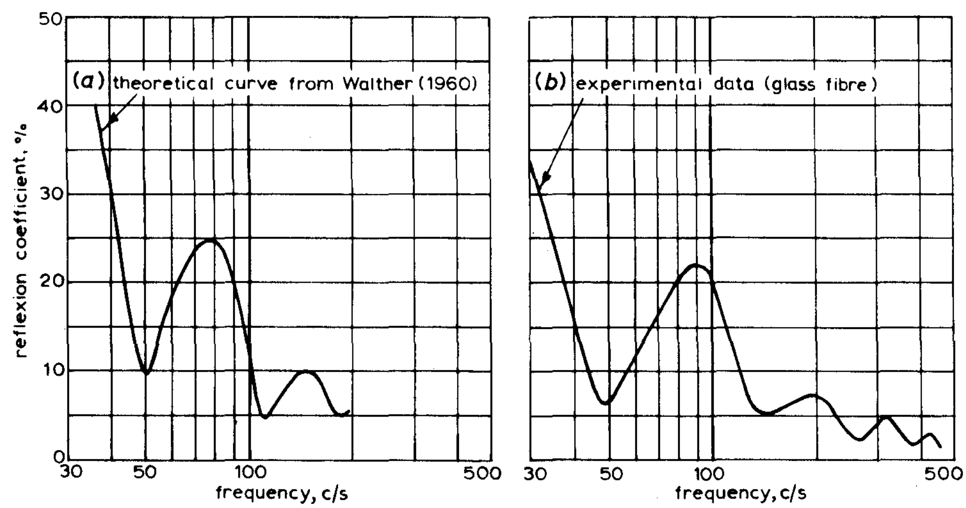

Fig. 2 - Reflexion Coefficient of Low Density Porous Wedges

(a) Theoretical Curve from Walther (1960) (b) Experimental data (glass fibre)

Although the reflexion characteristics of absorbent wedges do not always follow the theoretical form as closely as in the examples just given, the same general principles appear to hold. The experiments on fibrous materials yielded a number of conclusions, applicable to a wide range of materials, regarding the effect of varying the dimensions of the absorbent wedges and their spacing from the wall.

Fig. 3, for example, shows the effect of varying length of taper *A* on the reflexion characteristic of mineral wool wedges and Fig. 4 the effect of varying the air gap *C* for low-density glass-fibre wedges. Fig. 5 shows, for mineral wool wedges, the effect of varying the ratio *C/B* (air gap to parallel portion), keeping the rate of taper and overall depth of treatment constant.

Reflexion Coefficients

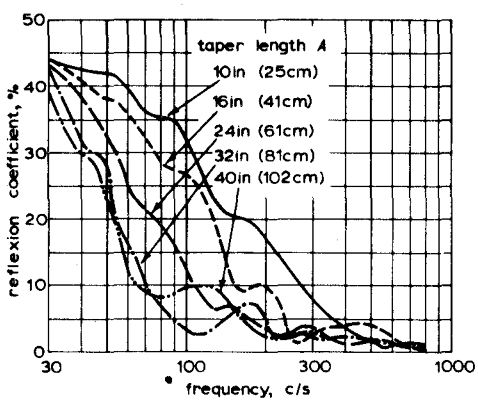

Fig. 3 - Variation with Length of Taper A for Wedges of Mineral Wool

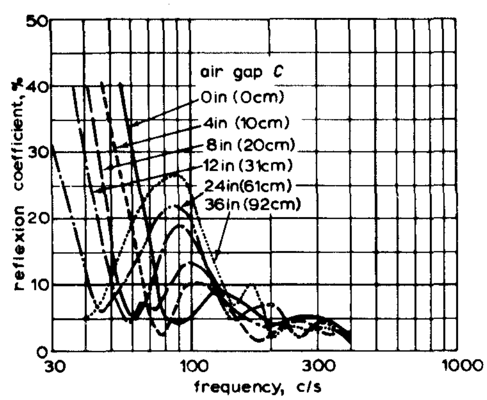

Fig. 4 - Variation with Depth of Air Gap C behind Wedges of Low Density Glass Fibre

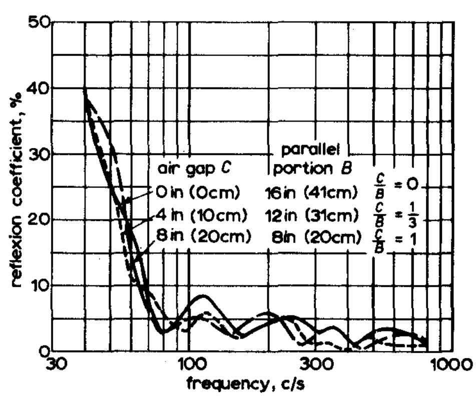

Fig. 5 - Variation with Ratio of Air Gap C to Parallel Portion B. Length of Taper A and Total Depth of Treatment D Constant. Wedges of Mineral Wool

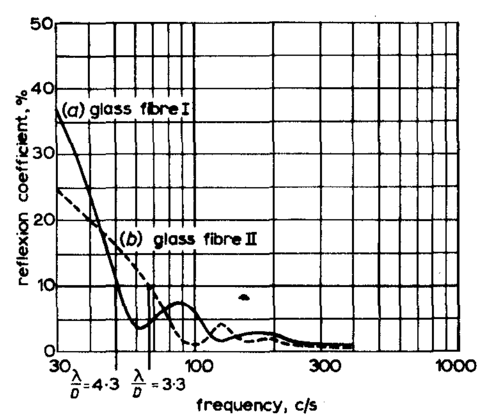

Fig. 6 - Wedges having Optimum Dimensions Low Density Glass Fibre

(a) I D = 60 in. (150 cm)
(b) II D = 60 in. (150 cm)

Of all the materials of this group, the best was found to be a particular grade of resin-bonded glass fibre, I, for which the reflexion characteristic with optimum wedge dimensions is given in Fig. 6 curve (a); λ_0/D is 4•3. Unfortunately, at this stage in the investigation the commercial production of this material ceased and the nearest substitute type glass fibre available, II, gave the characteristic, also shown in Fig. 6, curve (b), for which λ_0/D is only 3•3. Attempts were made to reduce the reflexion coefficient at low frequencies by constructing behind each wedge a Helmholtz resonator, the inlet of which was accommodated in a gap between adjacent wedges. No worthwhile improvement in performance was, however, achieved by this artifice.

4. FOAMED PLASTICS MATERIALS

Attention was then turned to foamed plastic materials, which have the advantage of being free from dust and not easily damaged in handling. The general principles, illustrated above, which govern the choice of wedge dimensions appeared to apply also to this class of absorbent material. A wide variety of plastic foams, both rigid and flexible, was tested, but in every case in which the performance looked promising, the reflexion characteristic was found to be profoundly affected by mechanical resonance in the body of the material. Fig. 7 shows, by way of example, the reflexion characteristic of a polyurethane foam, III, together with the output of an accelerometer applied to the wedge; for this material, if it were possible to ignore the rise in reflexion coefficient in the region of resonance, λ_0/D would be 3•8. For comparison, the reflexion characteristic of mineral wool wedges for which λ_0/D is 3•9 is also shown.

Mechanical resonance phenomena in the absorbent material are naturally affected by mechanical constraints, and the influence of these resonances on the reflexion characteristic thus depends a good deal on the method of mounting the wedges. As an example of this, Fig. 8 shows the effect of partially attaching polyurethane ester wedges, IV, to the wall by adhesive. The effect of the additional constraint is to reduce the value of λ_0/D from 4•3 to 2•4.

Reflexion Coefficients

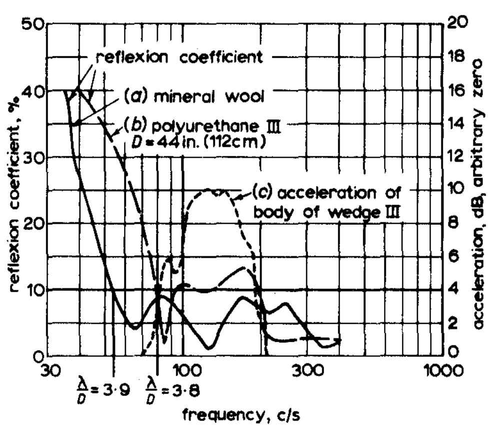

Fig. 7 - Wedges having Optimum Dimensions

(a) Mineral Wool. D = 60 in. (150 cm)
(b) Polyurethane Ether III. D = 44 in. (112 cm)

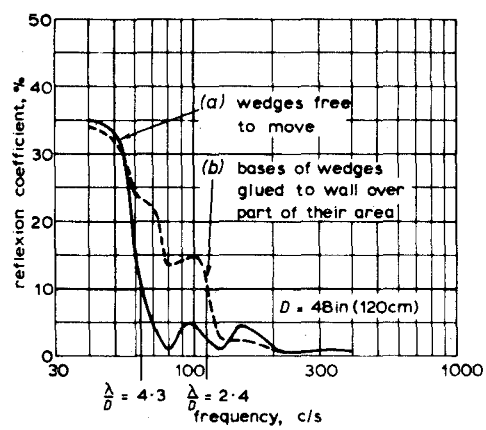

Fig. 8 - Polyurethane Ester Wedges IV for two boundary conditions

D = 48 in. (120 cm)

Most foam plastics have very little mechanical hysteresis; their internal resonances are therefore lightly damped and the effects of these are subject to wide variations in manufacture. As an example, curves (a) and (b) in Fig. 9 show the reflexion characteristics of wedges from two different batches of polyurethane ether foam, V, for which the best value of λ_0/D is 4•5.

Fortunately, in the course of the investigation a new type of polyurethane ether foam, VI, having an appreciable amount of mechanical hysteresis, became available. Fig. 10(a) shows the reflexion coefficient obtainable with this material, for which λ_0/D is 4•3; the effect of the increased damping is apparent. Foam VI was found to be sufficiently reproducible in quantity production and was therefore adopted for use in the new free-field room.

It was at first intended to mount the wedges by impaling each one on a ¼ in. (6 mm) diameter steel rod projecting from the wall, floor or ceiling. This form of support had, however, to be abandoned as the mechanical constraint so introduced adversely affected the performance of the wedges. Nevertheless, it was found that by leaving the steel rod in place but not attached to the wall, the value of λ_0/D could be increased, as shown in Fig. 10(b), to 4•8. Experiments made with rods of other materials showed that the mass of the rod rather than the stiffness was responsible for this effect.

Reflexion Coefficients

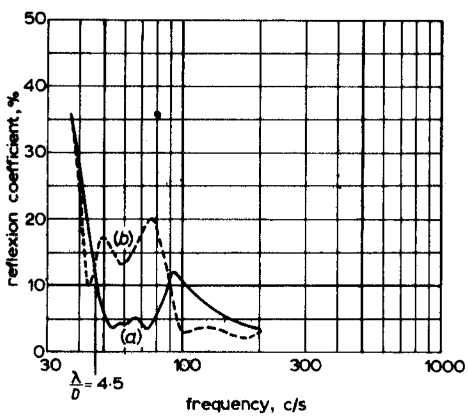

Fig. 9 - Polyurethane Ether Type V from different batches

D = 60 in. (150 cm)

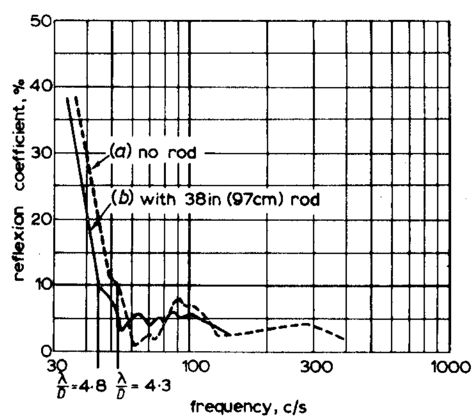

Fig. 10 - Polyurethane Ether Wedges VI as used for Free-Field Room, with and without Steel Rod

D = 60 in. (150 cm)

Measurement of the reflexion coefficient of wedges of foam VI was also made at frequencies above 800 c/s, the limit imposed by the onset of transverse resonance modes in the 16 in. x 16 in. (40 cm x 40 cm) test duct. To this end, a smaller duct, of internal cross section 4 in. x 2 in. (10 cm x 5 cm), was built, which allowed measurements to be made up to 4 kc/s. It was not possible to accommodate a complete wedge in this duct, but a sample was taken from the centre of the wedge, including the tip. The results thus obtained have been combined with the data from Fig. 10(b) to give the overall curve in Fig. 11.

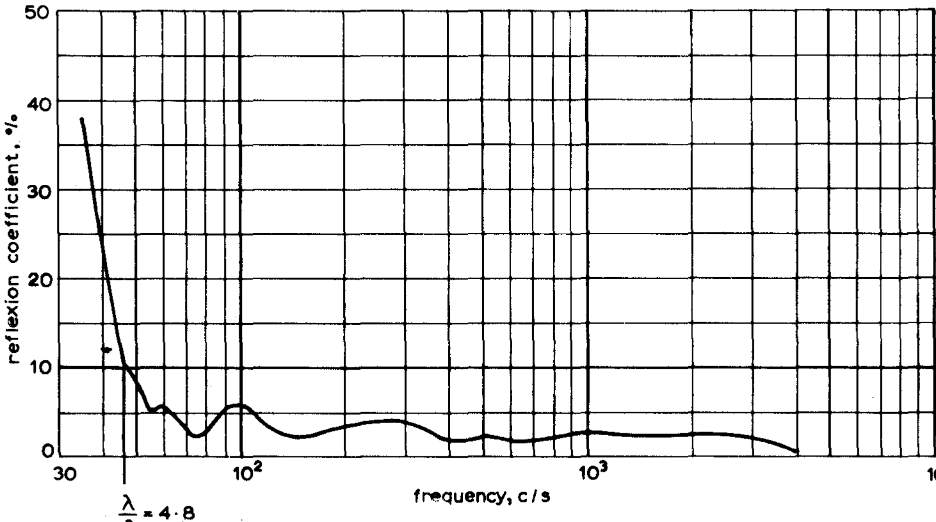

Fig. 11 - Typical Reflexion Coefficient of Polyurethane Ether Wedges VI as used for Free-Field Room D = 60 in. (150 cm)

To give some idea of the degree of reflexion to be expected when the sound approaches a bank of wedges at nearly grazing incidence, the tests above 800 c/s were repeated using sections of a wedge arranged with their side surface normal to the direction of sound incidence. The reflexion coefficient at frequencies up to 2·5 kc/s was less than 8% and fell at higher frequencies, as shown in Fig. 12.

As plastic foam is rather soft, it was necessary to provide some support to prevent excessive sagging. The method of achieving this is shown in Fig. 13. The position of the point of support was found to be important; any additional constraint in the neighbourhood of the wedge tip increased the reflexion coefficient in the region of 90 c/s; a similar effect appeared, as shown in Fig. 14, if the length of the steel rod was made too great.

To keep a check on the production variations of the material, sample wedges made from about 2% of each batch were tested before the remainder of the material was cut.

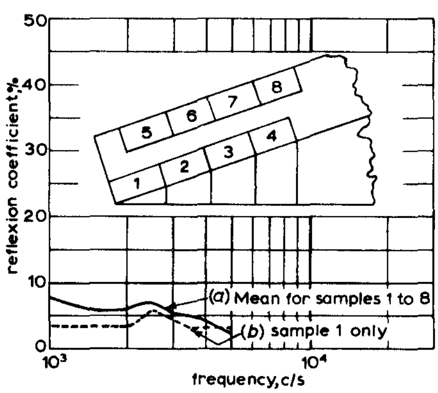

Fig. 12 - Reflexion Coefficient from side of Polyurethane Ether Wedge VI at High Frequencies

5. CONCLUSIONS

Not all types of plastic foam are suitable for sound absorbent purposes since their mechanical damping is frequently too low and the acoustic properties of the material may be very variable in large scale production; in fairness to the manufacturers, however, it should be remembered that most of these materials were never intended for sound absorption.

Certain types of polyurethane ether foam are, however, equivalent, as far as can be discovered from small scale tests, to the best of the fibrous absorbent materials. Final judgment on this matter must, however, await full-scale tests on the new free-field room which is now approaching completion.

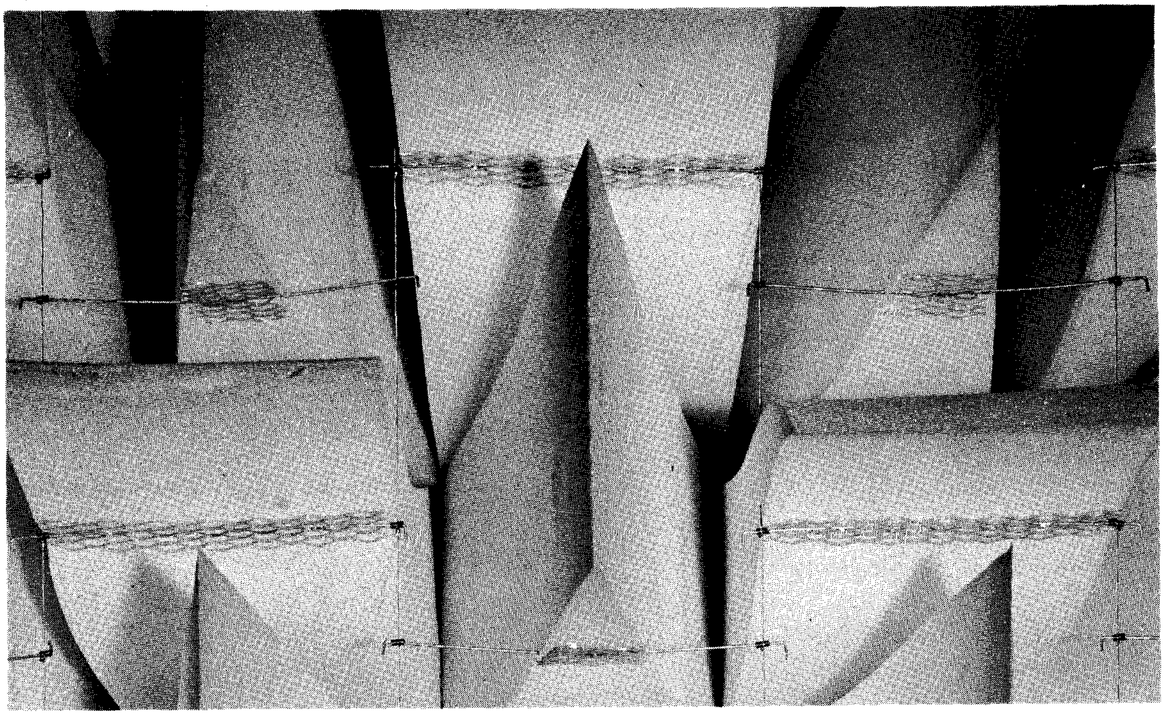

Fig. 13 - Method of Supporting Wedges to Prevent Sagging

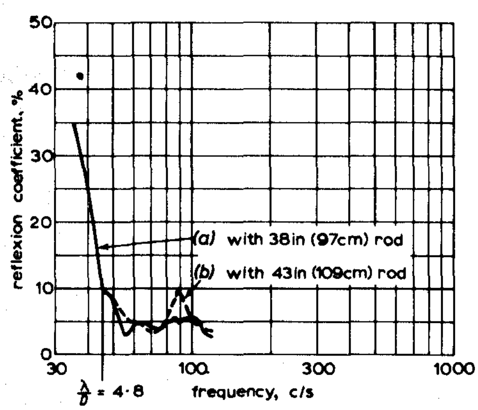

Fig. 14

Reflexion Coefficient of Polyurethane ether Wedges VI showing effect of increasing length of steel rod

D = 60 in. (150 cm)

6. ACKNOWLEDGEMENTS

Thanks are due to Mr. W.I. Manson and Dr. D.J. Neale, together with Messrs. R.L. Deane and K.H. Hewitt, for their assistance with the measurements.

7. REFERENCE

1. Walther, K., 'Reflection factor of Gradual Transition Absorbers for Electromagnetic and Acoustic Waves', I.R.E. Transactions on Antennae and Propagation, November 1960, page 608.

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Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey